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FINAL TECHNICAL REPORT

INVESTIGATION OF MODELS FOR LARGE-SCALE METEOROLOGICAL PREDICTION EXPERIMENTS

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Introduction

The project was initiated at The City College on 1 October 1973 under Grant NGR 33-013-086. The general objective of the research supported by the grant has been to investigate the feasibility of extended and long-range weather prediction by physical and dynamical methods. In pursuit of this objective, the project group has engaged in a close collaboration with the Goddard Institute for Space Studies (GISS), particularly in experiments with the GISS global general circulation model. The project staff provides technical support and consulting services to GISS in the areas of meteorological experiment, analysis, and interpretation, and, in turn, is provided by GISS with excellent computing services for its own prediction experiments. The project can truly be described as a cooperative effort between The City College and GISS.

During the past year, the project staff has consisted of the principal investigator, two graduate students (Gary Crane and Robert Atlas), a third graduate student (Shu-hsien Chow) for three months, who later was employed for 2 months as a post-doctoral associate, and part-time secretary and draftsman. (Mr. Crane resigned in July 1974 and was replaced in September 1974 by Eugene Kuo.)

Spectral Energy Balance Study

In April 1974 Mrs. Shu-hsien Chow completed a doctoral dissertation on " Effects of a Transient Sea Surface Temperature Anomaly on the Energetics of the Mintz-Arakawa Model Atmosphere" for her Ph. D. degree at New York University. This study was begun at the time the research project was located at New York University and it was completed after the principal investigator and the project transferred from NYU to The City College in September 1973.

The possible response of the atmosphere, as simulated by the two-level Mintz-Arakawa global general circulation model, to a "transient" warm sea surface temperature (SST) anomaly lasting for one month in the North Pacific Ocean was investigated in terms of the model energetics both in the spatial and wave number domains. In the first month of the simulated meteorological history, the increased heating, evaporation, and condensation over the local anomaly region apparently caused an increase in the diabatic generation of eddy available potential energy in northern middle latitudes. (The hypothetical "warm pool" added to the climatological sea surface temperature field was located between latitudes 22N-42N and longitudes 140W-180 in the mid-Pacific Ocean. The maximum SST anomaly in the warm pool was 6°C. For a further description of the hypothetical SST anomaly see Spar (1973 a, b).) The enhanced temperature gradient, especially on the northern side of the warm pool, was found to increase the eddy energy conversion at intermediate scales in northern middle latitudes. In the second month, on the other hand, the removal of the anomalous SST pattern appeared to cause a reduction in eddy activity in northern middle latitudes in all wave numbers. A large response to the transient North Pacific warm pool was also found in middle latitudes of the Southern Hemisphere during the second and third months. In general, the results indicate that transient SST variations of relatively large magnitude in the North Pacific Ocean can induce a disturbing effect on the global energetics both in the spatial and wave-number domains.

The ability of the two-level Mintz-Arakawa model to simulate the energetics of the real atmosphere was also examined in this study. Except in the tropics, the model did exhibit a realistic energy budget. However, a major defect of the model, which is apparently due to the parameterization of convection, is the production of excessive precipitation in the tropics. This in turn, affects all atmospheric energy transformations computed for the tropics.

Annual Cycles of Surface Heat Balance and Temperature Over North America

To provide a basis for thermodynamic prediction of mean monthly surface temperature anomalies over a large area, an effort was made to calculate a climatological surface heating function for North America from the mean annual surface temperature cycle and surface energy balance data. The heating function is defined, for the total continental area of North America between latitudes 30N and 60N, as the ratio of change of surface temperature to the surface heat balance. The temperature data were obtained from a recent climatic atlas (Crutcher and Meserve, 1970) and the energy balance data were derived from Budyko's (1963) heat balance atlas. Both sets of data were integrated over the total continental area for each month of the year.

The annual cycle of the surface heat balance, as derived from Budyko's maps of surface radiation balances, turbulent heat losses, and evaporative heat losses[1], was found to be inconsistent with the mean annual temperature cycle of the continental surface. As a result, the annual cycle of the surface heating function could not be evaluated. However, a mean annual value of the heating function was calculated from the annual temperature range of the continental surface and the cumulative surface heat balance over the 6-month-period from the coldest to the warmest month. This heating function was found to be about 12 degrees C per kilolangley for the North American continent. On the assumption of a constant heating function all

[1]The sum of the evaporative plus turbulent heat losses at the continental surface will be referred to as the "evapo-turbulent" heat loss.

year round, new values of the surface heat balance were then computed for North America for each month of the year by dividing the time derivative of the mean annual surface temperature cycle by the heating function.

The surface heat balance is the difference between the surface radiation balance, for which the annual cycle is reasonably well-known, and the evapo-turbulent heat loss, for which it is not. However, by using Budyko's data for the radiation balances, together with the recomputed surface heat balances, one may calculate the surface evapo-turbulent heat loss of the continent for each month of the year. The resulting annual cycle of the evapo-turbulent heat loss is at least as credible as that derived from Budyko's atlas.

The mean annual surface temperature cycle for the continent is the result of only a slight imbalance between the climatological radiative and evapo-turbulent heat fluxes, both of which are of approximately equal magnitude each month and just slightly out of phase. Thermodynamic prediction of monthly anomalies of surface temperature, based on observed or predicted anomalies in the two fluxes and on the climatological surface heating function, is thus a formidable problem because of the difficulty of evaluating anomalies in the surface heat balance.

(A paper by J. Spar and G. Crane, titled "A Note on the Annual Cycles of Surface Heat Balance and Temperature over a Continent", has been completed and will be submitted for publication.)

Atmospheric Response to Sea Surface Temperature Anomalies

An extended range prediction experiment was performed with the GISS 9-level global atmospheric general circulation model (Somerville, et al., 1974 on a global data set beginning 20 December 1972 to test the sensitivity of the model to SST variations over a two-week forecast period.

The GISS model is sensitive to SST anomalies in the sense that the convective precipitation forecast by the model is locally enhanced over the ocean in regions of moderately large positive SST anomalies. (Cold anomalies undoubtedly suppress convective precipitation in the model, but the data on cold cases were not sufficient to demonstrate this point.) However, while it was not possible to evaluate the effect of this enhancement on the quality of the forecasts over the ocean, the use of the observed rather than the climatological SST field had no positive effect on the quality of the precipitation forecasts over continental areas where the forecasts could be verified.

The mass fields forecast by the model, as represented by sea level pressures and 500-mb heights, are relatively insensitive to variations in sea temperatures. Effects of the SST anomalies grow very slowly for about a week compared with the rapid growth of prediction error. At the end of a week, the r.m.s. differences between forecasts made with and without SST anomalies are no larger than the corresponding r.m.s. forecast errors that developed within the first 12 to 24 hours. The effects of SST anomalies, like those due to initial random errors in the atmospheric fields, do grow much faster after the first week, but by then the daily forecast fields have no predictive value. An interesting sidelight of the experiment is the fact that the influence of random initial atmospheric errors decays rapidly within the first day of prediction compared with the growth of forecast error, but then grows at about the same rate as the effect of SST anomalies over the two week period.

Daily prognostic synoptic maps of sea level pressure and 500-mb height (as well as 850-mb temperature) are found to be virtually identical for about a week whether computed with climatological or observed SST fields. Similarly, prognostic 14-day mean maps of sea level pressure and 500-mb height (as well as 850-mb temperature) are also almost indistinguishable whether computed with climatological or observed SST fields.

R.M.S. errors in the 14-day mean fields of sea level pressure and 500 mb height are slightly smaller over the Northern Hemisphere when the forecast is computed with observed SST values than when climatological SST values are used. However, this result is not consistent for smaller areas, such as Europe and North America. Except for the European area, the forecast 14-day mean sea level pressure fields are better than persistence forecasts, but the best forecasts, compared with persistence, are those computed with climatological SST fields.

Provisionally, the experiments appear to suggest that observed SST fields contribute little or nothing to the improvement of forecast quality in the short and extended ranges. Any possible benefits gained from more accurate specification of the SST field appear to be overwhelmed by the decay of predictability before the diabatic effects associated with the SST anomalies are felt by the atmosphere. However, it should be noted that anomalies of larger magnitude than those used in this experiment do occur in nature and may have larger effects; that the GISS model may be too insensitive to surface fluxes and their anomalies; and that smaller scale anomalies, such as those associated with regions of large SST gradients (e.g., Gulf Stream meanders and eddies), may have more significant effects in a forecast computed with higher spatial resolution.

(A paper by J. Spar and R. Atlas, titled "Atmospheric Response to Sea Surface Temperature Anomalies", has been completed and will be submitted for publication.)

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